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AMERICAN SOCIETY OF CIVIL ENGINEERS.

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No. 874.

EXPERIMENTS ON THE PROTECTION OF STEEL AND ALUMINUM EXPOSED TO WATER.

By A. H. SABIN, Assoc. M. Am. Soc. C. E.

PRESENTED DECEMBER 20TH, 1899.

WITH DISCUSSION.

This paper states the results of the continuation of a series of experiments to determine the comparative durability of paints and varnishes, which experiments were begun in February, 1895, and were made the subject of a paper read before this Society on November 4th, 1896.* The plates described in that paper had been exposed to the action of sea water in the New York Navy Yard for a period of six months; those to be described now were chiefly triplicate sets, one set of which was exposed under the surface of the sea water in the New York Navy Yard, another was similarly placed in the Norfolk Navy Yard, while the third was placed in fresh water, in Lake Cochituate, near Boston, Mass. All were placed in the water during the last half of June, 1897. Those at Norfolk and Boston remained untouched until July, 1899, a little more than two years; but those in the New York waters were in cages suspended to a float which was accidentally sunk in July, 1898, and more than half the plates were lost; the remainder

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were taken out July 21st, 1899, after an immersion of exactly thirteen months.

The consent of the Navy Department was obtained for placing the plates in the Navy Yards, and in this whole matter the writer is under great obligations to Naval Constructor F. T. Bowles and Assistant Naval Constructor R. M. Watt, of the New York Yard, and to Naval Constructor A. W. Stahl, of the Norfolk Yard. The Boston set was placed by the courtesy of Desmond FitzGerald, President, Am. Soc. C. E., Engineer of the Sudbury Department, Metropolitan Water Board of Massachusetts.

The assistance rendered by these gentlemen was essential to carrying on the experiments. The frames or cages, containing the plates of steel and aluminum which had been painted, were placed in and removed from the water by their assistants; the New York plates, on removal from the water, were inspected by Mr. Bowles and Mr. Watt, also by representatives of some of the technical journals, and by several engineers; the Norfolk set was examined by Mr. Stahl and by an expert, under his directions. The Engineering Department of the Metropolitan Water Board had a representative on the ground to inspect the plates at Lake Cochituate, but, owing to unexpected difficulties encountered in getting the plates from the water, it was found inconvenient to make a local inspection.

With the exception of the ships'-bottom paints, which were applied in the New York Navy Yard, the work of preparing and applying the coatings was done by Edward Smith & Company, of New York City, who paid all the expenses incident to the whole work. The aluminum plates were furnished free of charge by the Pittsburg Reduction Company.

The plates were suspended in open cages or racks, and were in a horizontal position one above another, about 2 ins. apart. They fitted tightly in the racks, and each plate was supported at the four corners. The racks were suspended about 6 ft. below the surface of the water, but at Lake Cochituate they were laid on the bottom, which was hard, about 20 ft. below the surface, and the plates were vertical. Besides the plates lost at New York, one rack containing 25 plates was lost at Norfolk. It was suspended by two $\frac{3}{8}$-in. galvanized iron chains, which rusted off. This gives some idea of the severity of the exposure. All the Boston plates were recovered.

In the salt-water tests it was found that barnacles and other organisms attached themselves to the lower sides of the plates. In the Norfolk Navy Yard the action of these was so severe as to destroy the paint on the under sides of all the plates, with the exception of those coated with the Sabin Pipe Coating, which did not seem to be affected, although oysters 4½ ins. in length were found growing on it. When these were removed the coating was found to be intact. But with this exception, it should be remembered, in looking over Table No. 1, that only one side of the plates in the Norfolk set is described, the coatings on the other side being uniformly destroyed, while in the New York and Boston sets both sides of the plates are included in the description.

Such varnishes as are mentioned in this paper are made by melting, at a temperature of 700° to 900° Fahr., certain resinous substances, such as Kauri, Manila and Zanzibar resins, and the asphaltic mineral known as gilsonite; 100 lbs. of resin is usually melted at once, and to this is then added a quantity of linseed oil, also hot, the amount of which varies according to the kind of varnish to be made. If 20 galls. of oil is used the product is called a 20-gall. varnish; if 30 galls., it is a 30-gall. varnish; and so on. The mixture of resin and oil is heated for some hours until combination occurs, and the product is then thinned with spirit of turpentine, which is regarded as a vehicle. Varnishes made with 20 galls. of oil, and with Manila, Kauri and Zanzibar resins, would be designated as 20 M., 20 K., and 20 Z., respectively; and so on. Enamel paints are made by grinding pigments in these varnishes, exactly as oil paints are made by grinding the same pigments in linseed oil.

Inasmuch as it has been believed that the process of baking adds to the durability of these coatings, in a few cases duplicates were prepared, one of which was baked and the other allowed to dry at the ordinary temperature.

The general scheme was to apply to a set of four plates a set of three varnishes, 20 K., 30 K. and 40 K., and pure raw linseed oil. Then, for another similar set, these same liquids were mixed, by grinding with white zinc; another set was prepared with white lead; another set with ultramarine blue; another set with graphite; and so on. This ought to show whether one pigment is better than another, and which vehicle is the best. Besides these, plates were painted with

pure red lead in pure linseed oil, with two mixtures of red lead and white zinc, with purple oxide of iron (crocus) in oil, and with Prince's metallic oxide of iron, which is a very well-known pigment consisting of iron oxide mixed with various silicates, in oil.

Besides these coatings of known composition, two popular and widely-known proprietary paints, the Eureka paint and the graphite paint made by the Detroit Graphite Manufacturing Company, were tried. These oil paints and proprietary paints were presumed to afford a sort of standard by which the other coatings could be judged.

The coating material described in the table as "Spar," is one of the well-known class of spar varnishes used for exterior work, and the kind used was made by Edward Smith & Company. The "I. X. L. No. 2" is a well-known interior varnish. The substance indicated by the initials "D. M. C." is Edward Smith & Company's "Durable Metal Coating," which is a varnish in which a considerable amount of gilsonite has been substituted for a corresponding quantity of resin. "Parahydric" is a coating similar to "Durable Metal Coating," but containing less oil, and has been used in painting the interior of water-pipes. "S. P. C." is the Sabin Pipe Coating, a varnish enamel which is baked on at about 400° Fahr., and which has been used on some of the largest hydraulic works in this country and is largely used in coating pipes on United States naval vessels. "Keystone" is a well-known pigment, probably ground slate, and was used to furnish a pigment composed of silicates for comparison. The iron oxide used is the purest commercial sesquioxide, containing over 95% oxide of iron. The purple oxide of iron is oxide which has been subjected to prolonged heating, and is supposed to be anhydrous. The "iron oxide in shellac" mixture was prepared from a formula furnished by Naval Constructor Bowles; the shellac is pure "D. C. Shellac" in grain alcohol. The paints known as Rahtjen's, McInnes' and Holtzapfel, are anti-corrosive and anti-fouling ships'-bottom paints, and were furnished and applied by the New York Navy Yard.

The nomenclature and abbreviations of Table No. 1 are as follows:

20 K. = 20-gall. Kauri Varnish.
30 K. = 30 " " "
40 K. = 40 " " "
20 M. = 20 " Manila. "

30 M.	= 30-gall. Manila Varnish.
40 M.	= 40 " " "
20 Z.	= 20 " Zanzibar "
30 Z.	= 30 " " "
40 Z.	= 40 " " "
D. M. C.	= Durable Metal Coating.
S. P. C.	= Sabin Pipe Coating.
Um. Blue.	= Ultramarine Blue.
W. Z.	= White Zinc.
W. L.	= White Lead.
A.	= Pure Aluminum.
A. A.	= Aluminum Alloy, 95 per cent.

The plates used for the purpose were of uniform size, 12 x 20 ins.; part of them were aluminum and the remainder steel, about $\frac{1}{8}$ in. in thickness. Since it is well known that aluminum is not acted on by fresh water, the aluminum plates were all put in the New York and Norfolk sets. The plates numbered from 151 to 163, inclusive, in the New York set, correspond to those numbered from 176 to 187, inclusive, in the Norfolk set, and are pure aluminum; those numbered from 164 to 175, New York, correspond to 188 to 200, Norfolk, and are aluminum plates alloyed with 5% of other metal.

Besides these regular sets of plates, a cage containing 24 plates, part steel and part aluminum, which had in 1896 been exposed for six months in the New York Yard, and are described in the writer's paper in November, 1896, were again exposed with the New York set. Half of these were lost by the accident already referred to, but the remainder are described in Table No. 1. Of these, Nos. 104, 105, 113, 122 and 124 are aluminum,* and the rest are steel. All are distinguished in the table by the date (1896) after the number.

As two entire cages of steel plates were lost in the New York Yard and one in the Norfolk Yard, the descriptions of the aluminum and the "1896" plates have been put in the otherwise vacant spaces of the table. All the plates, except those coated with Sabin Pipe Coating, which had two coats, received three full coats, well dried between coats. The red-lead paint used weighed about 35 lbs. to the gallon, and was put on with the plate in a horizontal position, on the top side of the plate. After the paint had set, the plate was turned over and

* See paper already referred to.

the other side was painted. The steel plates were all of the grade known as pickled and cold-rolled, and were cleaned with a steel wire brush. They were not pickled after they had left the steel mill, but their surfaces were perfectly clean and bright after being brushed.

Results.

In most cases, the protective coatings seem to begin to deteriorate on the surface, which becomes rough; then little blisters appear, which are caused by the separation of the last coat from those beneath; finally the undercoat blisters, in which case it is found, almost invariably, that rust has formed under the blister. If, however, the coating is porous—and this seems to be the case with the ordinary oil paints—the water reaches the metal and causes rust. This throws off the paint film, and the corrosion spreads rapidly in this way.

Protective coatings, such as are applied with a brush, are of three classes:

1. Pigment paints, in which the vehicle or liquid part is either linseed oil (or an inferior substitute) or varnish, and with this liquid portion is mixed mechanically a powdered solid, usually a mineral substance ground to a fine powder;

2. Red lead, which is a mixture of red lead and linseed oil, and which does not dry by oxidation as do other oil paints, but sets like a cement; and

3. Varnishes.

The linseed oil in ordinary oil paints dries by the absorption of oxygen to a tough leathery substance, but the film thus formed is soft and gummy, and is quite porous. Pigment is added to the oil for three reasons. It makes the liquid thicker and more viscous, thus enabling the operator to put on a thicker film; it makes a harder film, which will better resist abrasion; and the particles of pigment tend to fill up the pores of the film, thus rendering it more continuous.

Varnish forms a much more continuous (less porous) film than oil, hence it is better adapted for use in paint, and this is shown conspicuously by an examination of these tests, where the oil paints have failed, without exception, while the corresponding varnish paints are, in most cases, in good condition. The character of the pigment does not seem to have much influence. All the oil paint samples were so badly rusted that differentiation among them was impossible. It may

be that an earlier inspection would have shown differences, but the present appearance of all these plates is so similar that it seems unlikely, and certainly the varnish paints do not show any great differences in the matter of the pigments, except that white zinc seems to be somewhat the best. The iron oxides, graphites, and pulverized slate are all alike. The red lead, in the Boston and New York sets, is far better than any of the oil paints. The mixtures of red lead and white zinc are markedly inferior to red lead alone. In the Norfolk test, which was much more severe, the red lead had finally been quite destroyed. Deterioration in the case of red lead seems always to start from centers. In the Boston set, the red lead seemed to be in pretty good condition, but would probably not have lasted more than a year or so longer. It shows numerous rust spots. The blisters all start from the metal. But most of the varnish paints are much better than the red lead.

A study of the varnishes applied without pigment seems to show that in the fresh-water exposure the process of baking was, on the whole, of advantage, but not greatly so. In the salt water, the unbaked varnishes were better than the same varnishes baked; this agrees with the results recorded in 1896. The Manila varnishes are distinctly inferior to the Kauri and Zanzibar; the "Durable Metal Coating" is best of all. This is doubtless due, in a large degree, to the fact that this varnish, which is intended especially for the protection of structural steel, is made with a heavy body, and the film is of greater thickness than is the case with varnishes intended for wood work. Its composition has also been very carefully studied and designed to secure great durability, which is of much less importance than other qualities in ordinary varnishes.

By far the best results, however, with the exceptions to be hereafter noted, were obtained from the best of the enamel paints. Here, also, the Manila varnishes are decidedly inferior, and, in the opinion of the writer, these should be excluded hereafter from any such tests, although they make a much better comparative showing on wood.

In the enamel or varnish paints, those made with the more elastic varnishes (those containing the most oil) are decidedly the better. The extreme durability of these is well shown by the "1896" plates. These were first exposed to the air two or three months, then they were in the sea water six months, then exposed to the air nearly a year,

then under water thirteen months, and have since been exposed to the air over sixteen months, making a total of four years, and they are still, to all intents, perfect.

It is true that the air exposures have been indoors, but it was in a building adjacent to a railroad yard, where unprotected iron and even nickel steel is covered with deep rust in two or three months, and the air is often so acrid as to cause coughing. Two years' continuous immersion in fresh water has not injured some of these enamels, and two years in the excessively severe exposure at the Norfolk Navy Yard has left several of them in good condition, a few being practically uninjured.

It is generally true of all the better class of coatings that corrosion begins at the edges of the plate. In the case of aluminum plates, it seems evident to the writer that some of these coatings, notably the "Spar varnish" and the "Durable Metal Coating" have been gradually thrown off by corrosion creeping from the edge, probably from some mechanical injury, under the varnish, a patch of which remains uninjured and apparently without deterioration on the middle of the plate. This fact should not be lost sight of in considering this matter, and is one of the points shown by an inspection of the plates, but not easily brought out in a description.

Undoubtedly, the most obvious and conspicuous, and the most instructive, fact, is the total and absolutely universal failure of linseed oil films, either alone or mixed with any of the numerous pigments which were tried, while the corresponding varnishes and enamel paints made with the same pigments are in fair to good condition. This confirms strikingly the opinion, long held by the writer and many others of greater experience, that varnish films are much more impervious and resistant than any others. The exceptional cases to be noted are:

First.—The "Sabin Pipe Coating," a baked enamel, which is so much superior to the others as to form a class by itself, and

Second.—The extraordinary showing made by pure shellac varnish in the Lake Cochituate test. Shellac varnish is simply a solution of shellac resin, which is chemically an acid substance, in alcohol.

There are many grades of shellac; the one used was what has for many years been known as "D. C." orange shellac, and it was dissolved in pure 97% grain alcohol. Being an acid substance, it is attacked and dissolved readily by the ammonia in the atmosphere. It

is removed easily by soap and water. It has never been considered a durable varnish as ordinarily used on wood work, and it does not stand at all in the sea-water tests, but two years' exposure under 20 ft. of fresh water does not seem to have injured it sensibly. This may be a very serious matter, for, while in this regard it is no better than some other varnishes, such as "Durable Metal Coating," which cost much less money, shellac varnish has some important and exceedingly desirable qualities, which no other varnish has. For example, occasionally, we are confronted with the problem of repainting a section of large water pipe which can be spared from use only a few days. The interior of this pipe is damp. The best that can be done with it is to get out most of the visible water, but the cold surface of the metal will always be damp. No ordinary varnish will stick to such a surface, and corrosion will probably be set up at once; no ordinary varnish, of sufficient durability to be worth putting on, will dry in the limited time at our disposal. Now, shellac is dissolved in a vehicle which has an intense affinity for water, and it is highly probable that a thin film of dew will be instantly absorbed, and will certainly be removed, by the evaporation of the slightly diluted alcohol; and shellac, if applied in a thin coat, dries with the greatest rapidity. Three coats may be applied in eight hours. There is no unpleasant or dangerous odor, though ventilation should be secured, both on account of the risk of fire and because working in an atmosphere of alcoholic vapor produces intoxication. It certainly seems from this test as though we would be justified in using shellac varnish in such a case. It is expensive, of course, and it is very likely that the cheaper grades, which are found in ordinary use to be very much inferior in durability, would not be so efficient. In any case it would not be necessary to use it where the conditions are such that some equally good but slower drying coating can be used.

The metal plates used in these tests were free from rust or scale, and showed in all cases the bright color of the metal. To prepare plates for a paint test, this is the only way which will give comparative results. The writer is positive about this. It is sometimes said that we do not get our metal in this condition when we paint it, and therefore it is proper to make tests on somewhat rusty iron, or on iron with mill scale on it. In the first place, we ought to get the iron in that clean condition, and the writer is not without hope of liv-

ing to see the day when it will be done, in the case of permanent structures; and secondly, he is satisfied, from many years' constant experience in such experiments conducted on a most extensive scale, that it is absolutely impossible to get uniform conditions with rusty metal. A dozen metal plates, even if cut from the same sheet, will not rust uniformly; one will throw off a scale and another will not. The mill scale on a plate will be almost entirely removed from part of a plate by passing it through bending rolls, while it will adhere firmly to another part of the same plate. If this plate had been cut up and used for tests, the paint on one piece would come off and on another would stay on, and the scale is always different on the two sides of a plate.

Exposure tests, such as these, are of much more importance than laboratory tests. The manufacturers of paints and varnishes, some of whom are probably the best experts in this matter, never depend on any but an exposure test. It is by no means impossible that rapid laboratory tests may yet be devised, but such crude ones as have been so far proposed are in most cases of little value. Such a test, for example, is that with caustic alkali. This is a substance unknown in Nature, and no good paint will stand it, while a perfectly worthless paint might be made which would stand it very well. A nitric-acid test is of the same sort. It will simply burn up any organic substance, and some of the best linseed oil paints will yield to it most readily. It would hardly be regarded as a fair test of the comparative health of a dozen human beings to administer to each of them a couple of ounces of nitric acid and keep watch to see which lived longest, yet probably each could take a few drops of it per day without inconvenience. This is about what many of these so-called paint tests amount to. Some laboratory tests are of considerable value, but none is conclusive.

It has frequently been objected to these submarine tests that they are of value only as regards the same conditions, and there is some justice in such a criticism; but it is much weakened by the obvious fact that there is a practical agreement between the fresh-water and the sea-water tests. The latter were most severe, but in most cases the difference has been one of degree only. And in the rather large experience of the writer and his associates, these tests seem to agree in general with aerial exposures, reasonable exception being made in the case of coatings intended expressly for marine or for aerial use.

TABLE No. 1.

Lake Cochituate, Boston.	401-20 K. No rust except where damaged along edges; many very small blisters.	404-20 M. Much rust; coating much injured.	407-20 Z. Not much corrosion, but coating about destroyed.
	402-30 K. Like 401, not quite so good.	405-30 M. Worse than 404; coating nearly destroyed.	408-30 Z. Like 407, but considerably better.
	403-40 K. Like 401.	406-40 M. Not quite so bad as 405.	409-Spar. Like 408, but perhaps a little better.
Navy Yard, Norfolk, Va.	301-20 K. 301 to 310, coatings not destroyed; all considerably injured; blistered in small spots; no considerable corrosion; 301 worst; 306 and 309 best, 307-8 not bad.	304-20 M.	307-20 Z.
	302-30K.	305-30 M.	308-30 Z.
	303-40 K.	306-40 M.	309-Spar.
Navy Yard, New York.	1 (1896)-W. L. in 20 K. Some rust along edges; otherwise in good condition.	16 (1896)-W. Z. in 20 M. One-fifth of one side rusted; all the rest in good condition.	47 (1896)-Spar. Coating firm and good; very little rust.
	2 (1896)-W. L. in 20 K. Like 1.	18 (1896)-W. L. in 8 M. Paint hard and firm; in good condition.	35 (1896)-S. P. C. A little corrosion near the edges; otherwise all right.
		20 (1896)-W. Z. in 30 Z. Good. No blisters; no rust.	113 (1896)-S. P. C. Two small blisters; otherwise good.
		22 (1896)-W. Z. in 20 Z. Good. Some corrosion along edges.	

TABLE No. 1—(*Continued*).

410- I. X. L. No. 2. About like 407.	413-D. M. C. Good, except where broken and injured along edges.	417-Parahydric. Numerous isolated rust spots about ¼ in. diameter; coating otherwise good.	Lake Cochituate, Boston.
411-Shellac. Very excellent condition.	414-D. M. C. Like 413.	418-Parahydric. Like 417.	
412-Raw Oil. Surface generally corroded; many tubercles.	415-D. M. C. Like 413.	419-Parahydric. Like 417.	
	416-D. M. C. Like 413.	420-Parahydric. Like 417.	
310-I. X. L. No. 2.	313-D. M. C. Many small blisters, in outer coat chiefly; very little corrosion.	317-Parahydric. Coating all on; no blisters.	Navy Yard, Norfolk, Va.
311-Shellac. Coating practically gone; badly rusted.	314-D. M. C. Like 313.	318-Parahydric. Like 317.	
312-Raw Oil. Coating destroyed; very badly rusted.	315-D. M. C. Like 313.	319-Parahydric. Like 317.	
	316-D. M. C. Like 313.	320-Parahydric. Like 317.	
124 (1896)-Spar, one side baked. Very few small blisters, otherwise perfectly good.	105 (1896)-Chromium oxide in 20 K., one side baked. A few blisters; otherwise in excellent condition.		Navy Yard, New York.
104 (1896)-W. Z. in 20 K., one side baked. Like 124.			
122 (1896)-W. Z. in 20 K., one side baked. Like 122.			

TABLE No. 1—(*Continued*)

Lake Cochituate, Boston.	421-S. P. C. Perfect, except where coating is in one or two places broken at edge with corrosion.	425-W. Z. in 20 K. Half the surface, along the edges, blistered, with rust underneath.	428-W. Z. in 20 M. Outer layer of coating nearly destroyed; under coat good.
	422-S. P. C. Like 421.	426-W. Z. in 30 K. Much better than 425; some blisters; little corrosion.	429-W. Z. in 30 M. A few slight rust spots; outer coat blistered.
	423-S. P. C. Like 421.	427-W. Z. in 40 K. Good condition; some blisters in outer layer of coating; no rust.	430-W. Z. in 40 M. About one-fifth rusted; thin rust. Blistered; outer coat chiefly.
	424-S. P. C. Like 421.		
Navy Yard, Norfolk, Va.	321-S. P. C. Perfectly good condition. See note in text.	325-W. Z. in 20 K. Blistered; not very good.	179 A-I. X. L. No. 2. Coating all gone.
	322-S. P. C. Like 321.	176 A-20 K. Three-fourths of coating destroyed; thin rust.	180 A-Spar. Two-thirds of coating gone, but one-third in the middle perfectly good
	323-S. P. C. Like 321.	177 A-30 K. Like 176.	181 A-D. M. C. One-fifth gone, one-fifth blistered; remainder good.
	324-S. P. C. Like 321.	178 A-40 K. Coating all gone.	182 A-S. P. C. One-tenth gone on one edge; remainder all right.
Navy Yard, New York.			154 A-I. X. L. No. 2. Varnish half gone. Corrosion not deep.
		151 A-20 K. Blistered along edges and a few spots. Varnish firm. Little corrosion.	155 A-Spar. Most of the varnish soft, but some not affected. Not badly corroded.
		152 A-30 K. Much corrosion; some deep. Coating half gone; remainder firm.	157 A-D. M. C. Twenty per cent. blistered around edges. Coating firm; not much corrosion.
		153 A-40 K. Badly corroded; coating nearly all destroyed.	158 A-S. P. C. Excellent. Coating not injured, except by accident in removing from frame.

TABLE No. 1—(*Continued*).

431–W. Z. in 20 Z. Not much rust; outer coat badly blistered; under coat slightly so.	436–W. Z. in 20 K., baked. Almost perfect; still shows glossy surface of varnish.	439–W. Z. in 20 M., baked. Good; coating brittle in places and shows deterioration.	Lake Cochituate, Boston.
432–W. Z. in 30 Z. Better than 431. Outer coat blistered.	437–W. Z. in 30 K., baked. Like 436.	440–W. Z. in 30 M., baked. A little better than 439.	
433–W. Z. in Spar. Like 432.	438–W. Z. in 40 K., baked. Like 436.	441–W. Z. in 40 M., baked. Almost perfect.	
435–W. Z. in Raw Oil. Four-fifths of surface badly rusted; deep corrosion.			
183 A–S. P. C. Perfectly good condition.	187 A–W. Z. in Spar. Like 184.	191 AA–I. X. L. No. 2. Coating all gone.	Navy Yard, Norfolk, Va.
184 A–W. Z. in 30 K. Fine; no rusting nor blistering.	188 AA–20 K. Coating all gone.	192 AA–Spar. Three-quarters gone; like 189.	
185 A–W. Z. in 40 K. Like 184, but discolored.	189 AA–30 K. Three-quarters gone; small patch in the middle all right.	193 AA–Spar. Like 192.	
186 A–W. Z. in 30 Z. Like 184.	190 AA–40 K. Half gone; like 189.	194 AA–D. M. C. One-third badly blistered from edges; remainder good.	
159 A–S. P. C. Like 158 A.	163 A–W. Z. in Spar. Not deeply corroded. Several large blisters; otherwise in good condition.	167 AA–I. X. L. No. 2. Considerable blistering and corrosion. Coating easily scraped off.	Navy Yard, New York.
160 A–W. Z. in 30 K. Upper side perfect; lower side slightly blistered. Coating hard.	164 AA–20 K. Badly corroded; three-fourths of the varnish destroyed.	168 AA–Spar. Like 167, but not badly corroded.	
161 A–W. Z. in 40 K. No blisters; otherwise like 160 A.	165 AA–30 K. Like 164 AA.		
162 A–W. Z. in 30 Z. Like 161 A.	166 AA–40 K. Badly blistered, but not badly corroded. Coating on one side firm; on the other soft.	169 AA–D. M. C. Many blisters: very little corrosion; coating generally firm.	

TABLE No. 1—(*Continued*).

Lake Cochituate, Boston.	442–W. Z. in 20 Z. baked. Nearly perfect.	445–W. L. in 20 K. Very little corrosion. Some superficial blisters.	449–Um. Blue in 20 K. Considerable rust; not deep; paint practically destroyed.
	443–W. Z. in 30 Z. baked. Excellent; no rust; blisters superficial and few.	446–W. L. in 30 K. Good condition; no rust. Some superficial blisters.	450 Um. Blue in 30 K. A little worse than 449.
	444–W. Z. in Spar, baked. Like 443, or better.	447–W. L. in 40 K. Like 446.	451–Um. Blue in 40 K. Worse than 449; deep rust.
		448–W. L. in Raw Oil. Much deep corrosion; about half the plate in good condition.	452–Um Blue in Raw Oil. Like 451; whole surface rusted.
Navy Yard, Norfolk, Va.	195 AA–W. Z. in 30 K. Good; blistered a little on the edges.	199 A A–S. P. C. Blistered a little from edges; otherwise all right.	
	196 AA–W. Z. in 40 K. Fine, but discolored; like 185.	200 AA–S. P. C. Like 199.	
	197 AA–W. Z. in 30 Z. Fine, but blistered a little along the edges.		351–Um. Blue in 40 K. Nearly all gone.
	198 AA–W. Z. in Spar. Like 197.		352–Um. Blue in Raw Oil. Coating all gone; very badly rusted.
Navy Yard, New York.	170 AA–W. Z. in 30 K. Very little corrosion. Blisters amount to 1%. Coating good.	174 AA–S. P. C. In perfectly good condition.	
	171 AA–W. Z. in 40 K. Good, but not equal to 170 AA.	175 AA–S. P. C. Like 174.	
	172 AA–W. Z. in 30 Z. No corrosion; no blisters; excellent condition.		251–Um. Blue in 40 K. Very many small blisters; very little corrosion.
	173 AA–W. Z. in Spar. About like 172.		252–Um. Blue in Raw Oil. Uniformly corroded; coating all gone.

TABLE No. 1—(*Continued*).

453-Graphite in 20 K.	457-Keystone in 20 K.	461-Iron Oxide in 20 K.	Lake Cochituate, Boston.
Very good; some small blisters.	Good condition; no rust; some small blisters.	Very little rust; small blisters in outer coat.	
454-Graphite in 30 K.	458-Keystone in 30 K.	462-Iron Oxide in 30 K.	
Like 453.	Like 457.	Better than 461; no rust.	
455-Graphite in 40 K.	459-Keystone in 40 K.	463-Iron Oxide in 40 K.	
Like 453.	A little rust; many small superficial blisters.	Like 462.	
456-Graphite in Raw Oil.	460-Keystone in Raw Oil.	464-Iron Oxide in Raw Oil	
Deeply and generally rusted; about one tenth of the paint still good.	Badly and deeply rusted; patches of paint still good.	Corrosion deep and general; paint all gone.	
353-Graphite in 20 K.	357-Keystone in 20 K.	361-Iron Oxide in 20 K.	Navy Yard, Norfolk, Va.
Three-quarters gone; much rust.	Coating blistered and one-quarter gone.	Pretty good condition; a few blisters.	
354-Graphite in 30 K.	358-Keystone in 30 K.	362-Iron Oxide in 30 K.	
Half gone; much rust.	Blistered, but not destroyed	Not quite as good as 361.	
355-Graphite in 40 K.	359-Keystone in 40 K.	363-Iron Oxide in 40 K.	
One-quarter gone.	Blistered, but not in bad condition.	Like 361.	
356-Graphite in Raw Oil.	360-Keystone in Raw Oil.	364-Iron Oxide in Raw Oil	
Nearly all gone; badly rusted.	All gone; badly rusted.	Like 360.	
253-Graphite in 20 K.	257-Keystone in 20 K.	261-Iron Oxide in 20 K.	Navy Yard, New York.
A few blisters; very little corrosion.	No corrosion; numerous very small blisters.	Blistered, but not very badly. Not much corrosion.	
254-Graphite in 30 K.	258-Keystone in 30 K.	262-Iron Oxide in 30 K.	
Like 253.	Like 257.	Like 261. Not deeply rusted.	
255-Graphite in 40 K.	259-Keystone in 40 K.	263-Iron Oxide in 40 K.	
No corrosion. Paint in good condition. Numerous very small blisters.	Like 257.	Like 262.	
256-Graphite in Raw Oil.	260-Keystone in Raw Oil.	264-Iron Oxide in Raw Oil.	
Uniformly corroded; coating all gone.	Coating destroyed and plate badly corroded.	Like 260.	

TABLE No. 1—(*Continued*).

Lake Cochituate, Boston.	465-Red Lead in Raw Oil. Paint still tough; looks well. Blisters from the bottom with slight corrosion beneath.	469-Eureka Paint. General corrosion; paint entirely destroyed.	
		470-Detroit Graphite. Like 469; paint nearly all destroyed.	475-International Holtzapfel. Like 469.
	467-Prince's Metallic in Raw Oil. About one-quarter deeply rusted; paint practically all gone.	472-Iron Oxide in Shellac mixture. Good condition; about 2% rusted.	477-Red Lead and W. Z. in Raw Oil. Many deep rust spots; about 5%; remainder good.
	468-Purple Oxide in Raw Oil. Like 467.		478-Red Lead and W. Z. in Raw Oil. Like 477. Not nearly as good as 465.
Navy Yard, Norfolk, Va.	365-Red Lead in Raw Oil. Coating destroyed; plate badly rusted.	369-Eureka Paint. Like 365.	374-McInnes' Paint. Like 372.
		370-Detroit Graphite. Like 365.	375-International Holtzapfel. Like 365.
	367-Prince's Metallic in Raw Oil. Like 365.	372-Iron Oxide in Shellac mixture. Paint destroyed; general, but not deep corrosion.	377-Red Lead and W. Z. in Raw Oil. Like 365.
	368-Purple Oxide in Raw Oil. Like 365.	373-Rahtjen's Paint. Like 365.	378-Red Lead and W. Z. in Raw Oil. Like 365.
Navy Yard, New York.	265-Red Lead in Raw Oil. Coating badly destroyed. Considerable corrosion.	269-Eureka Paint. Like 260.	274-McInnes' Paint. In good condition; no barnacles.
		270-Detroit Graphite. Like 260.	275-International Holtzapfel. Paint badly gone; much corrosion; many small barnacles.
	267-Prince's Metallic in Raw Oil. Like 260.	272-Iron Oxide in Shellac mixture. A few blisters; otherwise in good condition.	277-Red Lead and W. Z. in Raw Oil. Coating thin; gone in many places; considerable corrosion.
	268-Purple Oxide in Raw Oil. Like 260.	273-Rahtjen's Paint. Paint badly gone; considerable rusting. Many small barnacles.	278-Red Lead and W. Z. in Raw Oil. Like 277.

TABLE No. 1—(*Concluded*).

481-20 K., baked. Practically perfect; coating still glossy.	484-30 M., baked. Several deep spots of rust, coating badly blistered.	487-I. X. L. No. 2, baked. Like 481.	Lake Cochituate, Boston.
482-30 K., baked. Like 481.	485-30 Z., baked. Like 481.	488-Raw Oil, baked. Badly and deeply rusted. Two-fifths of the surface good.	
483-40 K., baked. Like 481.	486-Spar, baked, Like 481.	489-D. M. C., baked. Fine; a few small blisters in the outer coat.	
381-20 K., baked. Half of the coating destroyed; the rest good. Not much rust.	384-30 M., baked. Like 382.	387-I. X. L. No. 2, baked. Like 386.	Navy Yard, Norfolk, Va.
382-30 K., baked. Four-fifths destroyed; very little rust.	385-30 Z., baked. Like 382.	388-Raw Oil, baked. All gone; rusted.	
383-40 K., baked. Like 382.	386-Spar, baked. Nearly all gone; little rust.	389-D. M. C., baked. Three-quarters gone; remainder good; very little rust.	
281-20 K., baked. Plate thinly rusted along the edges.	284-30 M., baked. Many small and some medium-sized blisters. Not badly rusted.	287-I. X. L. No. 2, baked. Not much corrosion; very small blisters.	Navy Yard, New York.
282-30 K., baked. Small blisters, with thin rust beneath, over most of the plate.	285-30 Z., baked. Good condition. Very little rusting. Very small blisters.	288-Raw Oil, baked. Badly corroded. Coating destroyed.	
283-40 K., baked. Very small blisters; not much rust.	286-Spar, baked. Coating badly destroyed; much corrosion.	289-D. M. C., baked. Very many small blisters. Not very much corrosion.	

DISCUSSION.

Mr. Buck. L. L. BUCK, M. Am. Soc. C. E.—Have any of the specimens been tested by being placed in salt water so as to be exposed part of the time, and part of the time not exposed?

Some tests of paints on wires were made for the speaker by E. G. Freeman, M. Am. Soc. C. E. The wires were about No. 8 gauge and cut in lengths of about 6 ins. They were coated with different kinds of paint and were then fastened together snugly in bundles of seven. The interstices were filled and the bundles coated with paint outside. These bundles were fastened to a pile, under the resident engineer's office, midway between high and low water. They were protected from abrasion by floating matter, and were left in position for six months, but not in freezing weather.

The reason for making the test in this way was that the conditions obtained would approach, more nearly than any others, the conditions which would be met by the cables of the New East River Bridge. The wires were found to be corroded even inside, where the interstices had been filled with the paint. There were only one or two substances which stood the test. One, called "cable shield," the composition of which the speaker knows, but is not allowed to divulge, withstood abrasion and corrosion perfectly. This material was selected as the covering of the cables, although its application was somewhat difficult.

Has the author used Lucol oil in any of his experiments?

The speaker has had some trouble in having paint applied properly. Having secured an honest manufacturer and obtained from him the required paint, he has found that a further requisite was the right kind of a man to apply it. The speaker has had structures painted and has found that after six months the pigment could be rubbed off with the hand quite readily. In the next specification prepared by the speaker he has concluded to insert a clause requiring the paint manufacturer to have an inspector present all the time to see that the paint is properly put on. In this way it may be possible to fix the responsibility if the work is not satisfactory.

Mr. Hill. GEORGE HILL, M. Am. Soc. C. E.—The author has said that he considers these tests a fair criterion by which to judge of the sufficiency of the coating, as applied to structural material exposed to the air or the elements. What time relation is considered by him as existing between the exposure to fresh or salt water and the exposure which would exist, for instance, in the steel skeleton of a building surrounded with masonry? That is to say, if after an exposure of two years in water and one or two years to air most of the coating has dis-

appeared, how many years will it take to produce a like result if the material is partially protected from corrosion? Mr. Hill.

Further, would all the protective coverings show the same relative deterioration under the conditions existing in buildings as they show when subjected to the direct action of fresh and salt water?

During the past six years the speaker has had Lucol oil under observation, and has used it quite extensively (for the last three years exclusively for exterior work and metal covering), and has found that it gave better results than any of the other oils. The speaker would like to ascertain the author's general views in regard to oil as compared with varnish. If the author's statements in regard to recent structural work in New York City are taken without qualification, it may be said that the life of the largest, or best, office buildings will be about twenty years, if the conditions under which the exterior supporting columns are installed are such as to subject these columns to a certain exposure; that is to say, if they are placed with their outer edges from 8 to 24 ins. from the exterior walls. The general practice is not to make any special provision for protecting the columns.

The speaker recalls one case in which it was specified that the columns should be left with a space around them. This space between the column and the enclosing brickwork was to be filled in subsequently with Portland cement, which would be, without doubt, a sufficient protection if the column were not otherwise protected; but with a film of paint between the metal and the cement the speaker doubts the sufficiency.

In New York City the practice, which is nearly universal, is to use one of the paints or, occasionally, Smith's durable metal coating, but if these have a life of approximately only twenty years, the New York practice should change quickly.

The paper does not indicate what should be done, yet some lesson should be derived from these tests to show what the practice ought to be, for engineers do not want to build for only ten, fifteen or even twenty-five years.

F. W. Skinner, M. Am. Soc. C. E.—In New York City the general practice is to protect from moisture quite effectively certain parts of the steel work of office buildings. Most of the grillage foundations, for instance, are bedded in concrete, and frequently the metal surfaces are also plastered. The wall columns, in many cases, are only protected by paint, but in other cases there is a special protection. Mr. Skinner.

In the St. Paul Building, for instance, there is a tile casing around the columns and also a coating of asphalt, or some kind of fibrous material wrapped around them.

Thomas D. Pitts, Jun. Am. Soc. C. E.—The author states that in these experiments the plates exposed in fresh water were placed vertically, while those exposed in salt water were placed horizontally. Mr. Pitts.

Mr. Pitts. Was there any special reason for so placing the latter? There would necessarily be a deposit of silt on the upper surfaces of these plates which would measurably protect the coating. It would also prevent the growth of oysters, barnacles, seaweed, etc., which will not grow on surfaces where they cannot get a firm hold. Moreover, the silt deposit would not necessarily be uniform on all the plates, so that they would not all have the same degree of protection.

This being true, would not more uniform conditions be secured by placing all the plates vertically?

Mr. Tatnall. GEORGE TATNALL, M. Am. Soc. C. E. (by letter).—The subject of protective coatings for iron is one of great depth, the surface of which has been little more than scratched. The universal use of iron, for such diverse purposes divides the subject into a number of problems according to the exposure to which the iron is subjected.

The protection of ironwork exposed to ordinary out-of-door conditions of sunshine, rain, dew and variations of temperature is the most usual problem. The protection of ironwork in the indoor exposure incident to the roofs of trainsheds, foundries, shops and other manufacturing establishments, presents another and very different problem, wherein the absence of the direct heat and light of the sun, and the drenching of rain, is offset by the presence of deleterious and corrosive gases. The protection of the skeletons of steel-framed buildings forms a third distinct problem.

Two other very similar problems, and very dissimilar to the others, are the protection of ironwork submerged in water, and ironwork alternately submerged and exposed, as by the fluctuation of tides.

These problems present such dissimilar features that the results of tests under one, can by no means be taken as more than an indication of possible results under one of the others.

This paper presents some valuable and instructive data relative to the protection of iron completely submerged.

Charles B. Dudley, M. Am. Soc. C. E., Professor Spennrath and others have shown the effect of submersion in water on a linseed oil film, manifested in the softening, wrinkling and loss of adhesiveness of the film. This receives abundant confirmation in the blistering and separation of the coats, so frequently noted.

By far the greatest enemy to paint coatings on iron is the well-known and uncontrollable propensity of the metal to rust when in the presence of oxygen and moisture, which is so fierce as to produce, by some sort of endosmotic and exosmotic action, the rusting of the iron and deposition of the oxide on the outside, through the pores of protective coatings of other metals, such as tin, zinc or lead. Bright iron will not rust in an atmosphere of pure oxygen, nor will it rust when immersed in distilled water, and it is questionable whether the scanty amount of air ordinarily held in suspension by river or sea water would

be sufficient to make the test as severe as it would be under conditions part wet and part dry, or even under those of ordinary outdoor exposure. In support of this, it can be stated that similar plates, to the knowledge of the writer, covered with two coats of some of the same paints mentioned in these tests, passed to complete destruction in from 6 to 12 months in ordinary outdoor exposure. Mr. Tatnall.

Almost invariably, the protective value, to iron, of a good paint, is destroyed in outdoor exposure by the penetration of moisture and air through the pores of the coatings; causing the formation of rust spots, microscopical at first, but increasing in size and number, and spreading and joining together under the film, until it is thrown off in flakes or shreds, long before its good qualities as a paint have disappeared. On this account, the very able prize essay of Professor Spennrath, complete and exhaustive as it is, in relation to the paint film, is useless as regards the protective value of that film to the iron beneath it.

The large number of samples, in these tests of submerged exposure, in which it was noted that the coatings had been destroyed and very little or no rusting manifested, would seem to indicate that the processes of destruction were different in this than in other exposures. The film seems to have been destroyed before the rusting commenced, but how? The almost invariable presence of blisters, or separation of the two films from each other and from the metal, shows conclusively the same softening, loosening, and wrinkling action on these films, as occurred in the case of linseed oil films on glass submerged in water, in the experiments of Dr. Dudley. But it has certainly not extended so far as to effect complete separation of the films from each other or from the metal, or some half-peeled remnants would have been found.

The absence of any explanation for this rustless destruction of the film in submerged tests, as well as certain unexplained phenomena occurring in ordinary outdoor exposure, suggests the query, does linseed oil, by complete oxidation, by long submersion, by the presence of the naturally occurring chemical reagents, or by the combination of any or all of these causes, become to any extent soluble in water?

Although the varnish gums are exceedingly unreliable and uncertain, whether used on wood or iron, in ordinary exposures, it seems to be shown clearly by these tests that the addition of the best of them to linseed oil is of great benefit to the latter in resisting the soaking destruction of submersion, by whatever influences this may be caused.

Oscar Lowinson, Assoc. M. Am. Soc. C. E.—The speaker has made a number of tests of a new paint, and with a view to determining its resistance to moisture, and the effects of frost, a coat was applied to the outside surface of a porous jar which was afterward filled with a concentrated solution of sulphate of soda and the solution allowed to evaporate. After a period of two weeks the interior of the jar was full of crystals, and with the exception of half an inch from the top of Mr. Lowinson.

Mr. Lowinson

the outside, which had been carried over by capillarity, the surface was still intact and showed no signs of having in any way been penetrated. This experiment was repeated with the same jar half a dozen times with the same results. A corresponding jar to which no paint was applied emptied in about 30 hours, both the inside and outside being covered with sharp crystals.

In order to determine whether this material could be used as a substitute for furring, a brick coated with it on its top surface was plastered directly on the paint and immersed to one-half its depth in a vessel containing water, until all the water, including that which the brick absorbed, had been evaporated. This process took a week, and showed absolutely no effect on the plaster. The plaster adhered so strongly to the paint that it could not be dislodged without destruction.

A similar brick was plastered without paint, and in a week the plaster became loose and detached from the brick.

"Furring," which is used on the inside of exposed walls of buildings to prevent moisture from attacking the plaster and thereby disintegrating it or staining the finished wall surface, can be dispensed with by the use of this paint on the wall surface and the direct application of the plaster upon it. The speaker also uses it on the back of limestone set in masonry to prevent the discoloration of the wall, which occurs when any other cement than the expensive LeFarge is used.

The paint also appears to resist the attacks of moderate acids and alkalies, and herein differs apparently from the paints mentioned by the author.

Two coats were applied on a rusty, cast-iron, fire stand-pipe in front of a building in New York City where it has stood for a year without flaking or showing rust spots, and when last examined by the speaker it was still hard and adherent, and to all appearances had stopped oxidation.

The speaker has not been converted to the theory of the author that laboratory tests are not of much value. He firmly believes in exposure tests, but, in order to satisfy himself, deems it his duty, when examining a material like paint, to make such tests as he thinks would give an imitation of the action of the elements.

Mr. Sabin.

A. H. SABIN, Assoc. M. Am. Soc. C. E. (by letter).—None of the tests in this series was made with the samples alternately wet and dry. Some experiments, however, were made by the writer by coating bundles of wires, which were then attached to piles in the sea water in such a way that one end of each bundle was under water constantly, while the upper parts were exposed to the air at low tide. The conclusion reached from this and other experiments was, that the protective effect of the coatings was not lessened by the intermittent

exposure, but that damage was done by floating objects in the water which persistently batter off the coating at the water-line. If secured against such effects protection is possible. This is probably the reason why iron piles rust off near the water-line; they are constantly battered by logs of wood and other floating matter which the waves throw against them incessantly. Mr. Sabin.

One of the objects sought by placing the plates horizontally in salt water was to get a growth of marine organisms on one side of the plate, while the other (the upper) side was kept free and reasonably clean. There was no considerable deposit of silt on these plates. In this way the exact effect of the organisms could be determined. The plates put in fresh water were laid in a vertical position because it was unavoidable under the circumstances, but as fresh water organisms are comparatively rare and did not attack the plates, it was no serious objection. The most serious trouble in these experiments was the injury to the coating on the edges of plates caused by floating objects in the water. This was sufficient, in some cases, to obscure the real value of the coatings, which were removed mechanically from the edges toward the middle of the plates. The writer is of the opinion that, hereafter, plates to be tested, which should not be in any case less than $\frac{1}{8}$ in. in thickness, and should not be smaller than those used in this test—the larger the better—should each be put in a frame such as used for the slates of school children, in order to protect the edges as well as possible.

It is probably impossible to give any definite answer to Mr. Hill's question. The exposure in steel frame buildings is extremely variable. Good compact hydraulic cement mortar, unquestionably, affords a great deal of protection, because it is alkaline, and alkalies do not rust iron; and also because it prevents much circulation of air, though it does not do so absolutely. Ordinary lime mortar is so very porous that its value is much less; and brick and tile vary so much in porosity that no generalizations about them can be made. The care with which these are applied is also an important factor. It seems to the writer that the most important object to be sought in these cases is to keep the metal dry. It is not possible to keep a bridge or similar structure dry, but it is possible with the steel frame of a building; if it is dry it ought not to rust very fast. Foundations which are so placed as to be always damp should have their steel work bedded in cement, which should be of as perfect quality and as great thickness as possible.

The writer does not share in the prejudice which some have against painting metal which is to be covered with cement; it is not likely that the latter has any mysterious action on the iron, but acts as any other protective coating does; and it is well known that some paints which do not bear ordinary exposure last well under cement.

Mr. Sabin. The writer has not used Lucol oil, and hence has nothing more substantial than a prejudice against it. He has preferred to keep to the use of materials of known composition, and which he thinks have yielded the best results up to the present time. It is well known, as has been pointed out by Mr. Tatnall, that oil-paint films are somewhat porous, and are often thrown off by corrosion underneath; and it has been the writer's aim to produce films which would not be open to that objection, but would protect the metal until the film itself is completely destroyed. The object of this paper is to show how this may be accomplished by the use of well-known materials, combined by well-known processes.

The writer cannot at all agree with the statement that the use of varnishes is a matter of great uncertainty, but, in fact, believes the opposite, and desires by these tests to show what products are most suitable for use on engineering structures. Furniture made 150 years ago by the celebrated Martin, of Paris, is still distinguished by its beautiful varnish; while violins, ranging from 200 to 300 years old, are still covered with the varnish originally applied to them. Such material is worthy of systematic study.